The Ordovician–Silurian boundary in South America

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Synopsis

In South America late Ashgill rocks followed in the same succession by the early Llandovery are known only in the Precordillera of San Juan, Argentina. Early Llandovery fossils are known from the Puna Well, Argentina, the basal Trombetas Formation of Brazil, west of Lake Titicaca in Peru, and in the Merida Andes of Venezuela. Glaciogenic deposits of presumed Ordovician–Silurian boundary age are known from Argentina, Bolivia, Brazil and Peru.

Introduction

There are unfossiliferous and relatively unfossiliferous strata in South America whose assignment to either the Ordovician or Silurian is a problem. But I am unaware of any South American area where there are *fossiliferous* strata involved in real Ordovician–Silurian boundary indecision. In South America the assignment of fossiliferous beds to either the Ordovician or Silurian has been easy because there are no areas recognized to date where fossiliferous beds of latest Ordovician and earliest Silurian age are present in conjunction with each other.

Discussion of the Ordovician–Silurian boundary in South America may be broken into two parts: (1) the strata present on the shield areas; (2) the strata present in the structurally complex Andean regions bordering the shield areas to the north and west. Recognized, fossiliferous Ordovician rocks have not yet been shown to exist on the shield areas except for a few areas very close to the Andean, disturbed rocks, whereas there is widespread Ordovician scattered here and there in the Andean regions; fossiliferous Silurian rocks are widespread on the shield areas, as well as in the Andean regions. There are potentially Ordovician, unfossiliferous strata, possibly latest Ordovician, rocks on the shield areas, but until some means of dating them precisely emerges it would be futile to spend time discussing them. For example, Caputo & Crowell (1985) have described diamictites that may be tillites of Ashgill age, that occur not too far below Silurian strata containing higher land plant spores of earlier Llandovery age (Gray, unpublished data from the Amazon Basin). I will, as stated, not devote attention to such difficult and biostratigraphically ambiguous beds.

In the following summary statement I will review, geographic region by geographic region, what is currently known about the lowest Silurian and highest Ordovician fossiliferous rocks of the continent. It should, however, be kept in mind that the later Ordovician and earlier Silurian of South America are very poorly known, or known only in a rough reconnaissance manner, when contrasted with rocks of similar age in Europe. Conclusions arrived at here, particularly in the many poorly understood Andean regions, will certainly be subject to serious revision during the next few decades as additional field and laboratory studies take place.

The Silurian correlation chart for South America (Berry & Boucot 1972) provides a good summary of the data available up to about 1970, but can now be significantly supplemented by additional published and unpublished data. Extra new data are also published by Cuerda *et al.* and Baldis & Pöthe de Baldis (this volume, pp. 291–295).

Argentina

Amos (*in* Berry & Boucot 1972) provided an authorative review of the Argentinian Silurian, and its relations with the underlying Ordovician where present. The Argentinian Palaeozoic may be easily divided into that associated with the Andes in the north and the west, as contrasted with that present on the shield areas to the east. Much of the shield area Palaeozoic in Argentina is present in the subsurface beneath Mesozoic and Cenozoic cover, but there are

limited areas where high-angle faulting has brought Precambrian and Palaeozoic rocks to the surface.

The shield regions in the Buenos Aires, La Pampa and Rio Negro regions (Amos *in* Berry & Boucot 1972: fig. 2) have not yielded any body fossils of proved Ordovician age, although some unfossiliferous units have been assigned for varied reasons to the Ordovician. Fossiliferous Silurian rocks are present in these regions, but no fossils of proved Lower Llandovery age have been demonstrated. The Silurian fauna consists of Malvinokaffric Realm brachiopods for the most part, and, as is characteristic of that cool to cold climate Realm, few taxa are present. It is presently unclear in these regions whether strata that could conceivably have crossed the Ordovician–Silurian boundary are present. The prevalence of late Ordovician to earlier Silurian continental glaciation in the Southern Hemisphere opens up the possibility that any such beds might well be in the non-marine category that can only be dated with a certain level of uncertainty for this time interval. The presence in the Cape Mountain System (Gray *et al.* 1986) of nearshore marine and possibly non-marine beds of probable Lower Llandovery or Ashgill age, or both, has some bearing on the Argentinian shield type occurrences in the Sierra de la Ventana, to the southwest of Buenos Aires in the Sierras Australes, which are commonly considered to be a pre-Jurassic continuation of the Cape Mountain System by many. In any event, it is reasonable to conclude (in the total absence of any dated Ordovician or early Llandovery fossils) that non-marine, or very nearshore, relatively unfossiliferous boundary beds might have been, or still might be present in the shield portions of Argentina. More subsurface data could demonstrate this possibility, particularly through the use of palynomorphs.

For purposes of considering the Ordovician–Silurian boundary, the Andean regions of Argentina should be divided into the Precordillera de San Juan, where the Cambrian and Ordovician fossils have North American platform biogeographical affinities and occur in platform carbonate type rocks, and the Andes proper with their Malvinokaffric Realm Ordovician and Silurian faunas occurring in siliciclastic rocks.

Amos (*in* Berry & Boucot 1972) has provided a summary for the Silurian of the Precordillera de San Juan. Nowhere are there fossiliferous Silurian rocks suspected to be older than Upper Llandovery, and the underlying Ordovician is nowhere thought to be younger than Caradoc, i.e. the Precordillera de San Juan is not a place in which to find a close approximation to the Ordovician–Silurian boundary as far as was then known, but see Cuerda *et al.* and Baldis & Pöthe de Baldis (this volume). The only exception to this statement about the absence of the Ashgill is in a limited area, where the Cantera Formation (Furque & Cuerda 1979: 473) has yielded Ashgill trilobites and brachiopods (Baldis & Blasco 1975; Nullo & Levy 1976; Levy & Nullo 1974), although interrupted above by '*contacto tectonico*' with a Lower Devonian unit. Tillites are not reported from this region, which suggests that the area may not necessarily have been subjected to continental glaciation, and might have been the site of a major regression associated with the terminal Ordovician–earliest Silurian glaciation.

Amos (*in* Berry & Boucot 1972) has summarized the Andean Silurian of northwestern Argentina, chiefly in the Provinces of Salta and Jujuy. The fossiliferous Silurian is no older than about Upper Llandovery based on available data, except for the single Lower Llandovery fossiliferous occurrence in the Puna well to the west of the material summarized by Amos (see Boucot *et al.* 1976). This fossiliferous Silurian is underlain by the tillites of the Mecoyita Formation which lack diagnostic fossils, and have been commonly considered (Laubacher *et al.* 1982) to be of Ashgill age (although shown by Amos, *in* Berry & Boucot 1972, to be well up into the Upper Llandovery). The underlying fossiliferous Ordovician is nowhere demonstrated to be of Ashgill age, although Caradoc equivalents are recognized (Amos *in* Berry & Boucot 1972).

It is clear that there are few places anywhere in Argentina for a palaeontologically-based close approach to the Ordovician–Silurian boundary.

Bolivia

Fossiliferous Ordovician (Hughes 1981, summary) and Silurian (Laubacher *et al.* 1982) rocks are well known in the Andean portions of Bolivia. However, no proved fossiliferous Silurian of

Lower Llandovery age is known, nor fossiliferous beds of Ashgill age. Tillite separating fossiliferous rocks belonging to the two systems is widespread. The oldest fossiliferous Silurian at present recognized is of Upper Llandovery age (Berry & Boucot 1972) from the Pojo region, where both brachiopods and graptolites provide the date. It is likely that there is a major, glacially correlated disconformity over most of Bolivia between the two systems (Berry & Boucot 1972: fig. 2). There is no reliable palaeontological evidence for placing any of the Andean tillites above the Llandovery: Berry & Boucot (1972: 26–27) summarize the graptolitic and brachiopod evidence from the overlying Kurusillas and Llallagua Formations, which contradicts that provided by Crowell *et al.* (1980); Crowell *et al.* (1981) suggest a Wenlock or Ludlow lower limit based on palynomorphs. An Ashgill age is most consistent for these tillites, in view of the overall emphasis on a glacial peak during that interval as contrasted with earlier Ordovician and later Silurian times. Antelo (1973) described Llandovery fossils from the Cancaniri, but the fossils actually come from above the tillite horizon (Cuerda & Antelo 1973) in beds which at Pojo were assigned by Berry & Boucot (1972) to the Llallagua Formation, which overlies the tillite proper.

Brazil

Fossiliferous Ordovician from the shield areas is unknown, except far to the west in the Amazonian region in the subsurface close to the areas of Andean disturbance. Silurian (Lange, *in* Berry & Boucot 1972) has been known from the Brazilian shield areas for over a century, but the graptolitic Silurian featuring *Climacograptus* has been conventionally assigned to the Llandovery, and not the latest Llandovery, because that genus was unknown above the Llandovery in the classic European and North American areas. Since 1972 there has been an accumulation of data indicating that *Climacograptus* can occur as high as the Lower Devonian (Jaeger 1978) in Austria, and that the palynomorphs associated with the graptolite show that the graptolites are no older than about Ludlow, rather than being of Llandovery age as had always been assumed. The palynomorphs in the Amazon Basin, where they occur with the graptolite, include acritarchs being studied by Luis Quadros, chitinozoans being studied by Florentin Paris, and higher land plant spores being studied by Jane Gray. All three specialists concur in assessing the age of the graptolitic part of the Trombetas Formation, the unit in question, as being no older than Ludlow. There is a possible tillite beneath the Trombetas Formation (Caputo & Crowell 1985). The tillite and associated strata are unfossiliferous, but an Ashgill age has been inferred, largely because the overlying, fossiliferous Trombetas Formation was concluded earlier to have been of Lower Llandovery age; this is now known to be an error. But basal Trombetas Formation beds, strata lacking any marine megafossils or marine palynomorphs, have yielded spore tetrads to Jane Gray which are of earlier Llandovery age and which also indicate in the absence of any marine organisms a possible non-marine environment. Similar spore tetrads of similar age have been recovered from the Brazilian Paraná Basin (Gray *et al.* 1985) and from the Cape Mountain System of South Africa (Gray *et al.* 1986).

Silurian strata have been reported from the Parnaiba Basin (Lange *in* Berry & Boucot 1972 gives a summary) based on palynomorph studies. However, there is still uncertainty about the precise parts of the Silurian present within this Basin, and no fossils of proved Ordovician age are known.

Fossiliferous Silurian was unknown in the Brazilian part of the vast Paraná Basin until this decade (see Gray *et al.* 1985, for a summary, including the initial recognition of these beds and their fossils by de Faria). Now, with the aid of both acritarchs and higher land plant spore tetrads there is no doubt about the presence of shallow water, Benthic Assemblage 1, marine earlier Llandovery on the northeastern flank of the Basin. Earlier Silurian, based on graptolites from the southwestern flank of the basin in Paraguay, has been known for some time (Harrington *in* Berry & Boucot 1972), but no trace of any fossiliferous Ordovician is known anywhere to be associated with the Paraná Basin.

In summary the Brazilian shield areas are not ones where the Ordovician–Silurian boundary may be located by means of fossils, owing to the total absence of any Ordovician fossils immediately beneath the available Lower Silurian fossils.

Chile

Fossiliferous Silurian rocks are unknown in Chile. The rocks from the Salar de Atacama region in northern Chile, assigned by Cecioni & Frutos (1975) to the Lower Palaeozoic (Ordovician, Silurian and Lower Devonian) are probably of Lower Carboniferous age, due to the similarity of their brachiopods to those found nearby (Bahlburg *et al.* 1986) which were assigned by Boucot to the Lower Carboniferous (fossiliferous Devonian beds are known from this area, yielding *Tropidoleptus* and *Australocoelia*, but these shells are unlike those figured by Cecioni & Frutos 1975 as contrasted with the Lower Carboniferous brachiopods). Fossiliferous earlier (Arenig) Ordovician is known in the Puna de Atacama, well to the east of the Salar de Atacama, but unassociated with fossiliferous Silurian. The nearest fossiliferous Silurian consists of a single Lower Llandovery locality in the Argentinian Puna, which yielded *Cryptothyrella* among other things (Boucot *et al.* 1976), which is unassociated with any fossiliferous Ordovician. The fossiliferous Devonian beds in the Salar de Atacama region are no older than about Siegenian–Emsian, and rest unconformably on an older basement complex. We do not know whether there is any possibility of finding Ordovician–Silurian boundary region strata in Chile. The older Palaeozoic rocks of Chile are almost unknown, although there are many suspect regions that warrant careful attention.

Colombia

Fossiliferous Silurian rocks are presently unrecognized in Colombia, while none of the known Ordovician has been shown to even reach the Caradoc, much less the Ashgill (Hughes 1981). The presence in the Perija Andes, on the Colombian–Venezuelan boundary, of Lower Devonian fossiliferous beds, resting unconformably on basement complex, indicates that at least in some spots one would not expect fossiliferous Silurian or Ordovician strata to be preserved.

Ecuador

Fossiliferous Ordovician and Silurian rocks have not yet been recognized in Ecuador, although there is no reason to doubt their potential presence in the Andean part of the country.

Paraguay

See discussion of the Paraguayan Lower Silurian occurring on the southwestern margins of the Paraná Basin under 'Brazil', p. 287.

Peru

There is widespread fossiliferous Ordovician and Silurian in southern Peru, both to the east and west of Lake Titicaca (see discussion of the Silurian in Laubacher *et al.* 1982; Hughes, 1981, summarizes the Ordovician, which has reliable palaeontological evidence only up to beds of Caradoc age). Laubacher *et al.* (1982) recognized Early Llandovery brachiopods to the west of Lake Titicaca, in the absence of the tillite that so commonly separates fossiliferous Ordovician and Silurian rocks from each other in the central Andean region. But these fossiliferous Early Llandovery fossils are removed stratigraphically some distance from the youngest Ordovician rocks which have yielded fossils no younger than Caradoc. In southern Peru, therefore, there is no locality known where a close approach to the Ordovician–Silurian boundary is made within fossiliferous rocks. In central and northern Peru, as well as along the coast, fossiliferous Silurian rocks are unrecognized. The lack of tillite to the west of the Titicaca region does raise the possibility that an Ordovician–Silurian transition may eventually be discovered in southern Peru or adjacent Bolivia, since a major disconformity might be more likely in the more easterly regions characterized by tillite.

Venezuela

The Ordovician and Silurian rocks related to the Ordovician–Silurian boundary are restricted in their occurrence to the Merida Andes, well to the south of Lake Maracaibo. Hughes (1981) comments that the Ordovician faunas of the Merida Andes are of Caradoc age; they are structurally well removed by faulting from immediate contact with the Lower Llandovery faunas of the Merida Andes described by Boucot *et al.* (1972). The Lower Llandovery faunas of the Merida Andes are dominated by brachiopods that cannot be dated any closer than Lower Llandovery; thus we are ignorant about whether or not these faunas are actually very close to the Ordovician–Silurian boundary. Graptolites that might help to resolve the age problem are unknown from the Merida Andes Llandovery. The shallow water nature of the Merida Andes Lower Llandovery, the medium-grained sandstones of the Silurian portion of the Caparo Formation with a Benthic Assemblage 2 set of communities dominated by such genera as *Mendacella*, is, however, consistent with the concept that there might be a disconformity between the two systems there, related to possible glacial regression, as is the case in many other parts of the world. In any event, the recognition of a close approximation to the Ordovician–Silurian boundary in Venezuela is as yet unknown.

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